



(10) **Patent No.:** US 9,276,410 B2  
(45) **Date of Patent:** Mar. 1, 2016

(58) **Field of Classification Search**

CPC ..... H02J 3/383; H02J 3/32; H02J 7/345;  
H02J 7/34; H02J 7/35; Y10T 307/615; Y10T  
307/724; Y10T 307/70

USPC ..... 307/46, 64, 82, 85  
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,369,210	A	2/1968	Manickella
3,596,229	A	7/1971	Hohorst

(Continued)

FOREIGN PATENT DOCUMENTS

CN	1309451	A	8/2001
CN	1122905	C	10/2003

(Continued)

## OTHER PUBLICATIONS

GB Combined Search and Examination Report—GB1203763.6—  
Mailing date: Jun. 25, 2012.

(Continued)

*Primary Examiner* — Carlos Amaya

(74) *Attorney, Agent, or Firm* — Banner & Witcoff, Ltd.

(57) **ABSTRACT**

A system for providing power from a direct current (DC) source to the power grid. The system includes a first inverter with an input and an output. The input is adapted to connect to the DC source. A first switch disposed between the output and the power grid. A second inverter with a DC terminal and an AC terminal, the AC terminal is adapted to connect in parallel with the output of the first inverter. A battery adapted to connect to the DC terminal of the second inverter. A second switch connected between the DC terminal of the second inverter and the input of the first inverter. The second switch also operatively connects the DC source to the battery. The system may further include a charging circuit adapted to be disposed between the input and the DC terminal and a load adapted to connect to the output.

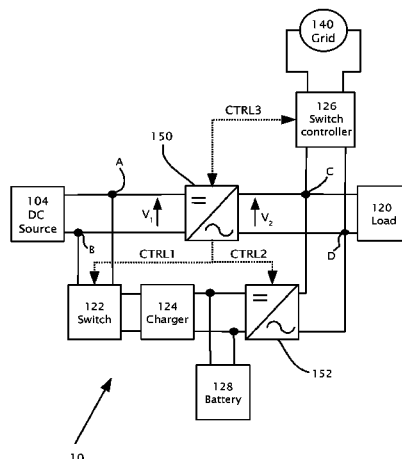
(60) Provisional application No. 61/265,734, filed on Dec. 1, 2009.

(51) **Int. Cl.**  
*H02J 7/00* (2006.01)  
*H02J 9/00* (2006.01)  
 (Continued)

(52) **U.S. Cl.**  
CPC . **H02J 3/383** (2013.01); **H02J 7/35** (2013.01);  
*Y02E 10/563* (2013.01); *Y02E 10/566*  
(2013.01);

(Continued)

**20 Claims, 5 Drawing Sheets**



(51)	<b>Int. Cl.</b> <b>H02J 3/38</b> <b>H02J 7/35</b>	(2006.01) (2006.01)	5,821,734 A	10/1998	Faulk
			5,822,186 A	10/1998	Bull et al.
(52)	<b>U.S. Cl.</b> CPC ..... <i>Y10T 307/336</i> (2015.04); <i>Y10T 307/615</i> (2015.04); <i>Y10T 307/625</i> (2015.04); <i>Y10T</i> <i>307/707</i> (2015.04)		5,838,148 A	11/1998	Kurokami et al.
			5,869,956 A	2/1999	Nagao et al.
			5,873,738 A	2/1999	Shimada et al.
			5,886,882 A	3/1999	Rodulfo
			5,886,890 A	3/1999	Ishida et al.
			5,892,354 A	4/1999	Nagao et al.
			5,905,645 A	5/1999	Cross
			5,917,722 A	6/1999	Singh
			5,919,314 A	7/1999	Kim
			5,923,158 A	7/1999	Kurokami et al.
(56)	<b>References Cited</b>  U.S. PATENT DOCUMENTS		5,932,994 A	8/1999	Jo et al.
			5,933,327 A	8/1999	Leighton et al.
			5,945,806 A	8/1999	Faulk
			5,949,668 A	9/1999	Schweighofer
			5,963,010 A	10/1999	Hayashi et al.
			5,990,659 A	11/1999	Frannhagen
			6,002,290 A	12/1999	Avery et al.
			6,031,736 A	2/2000	Takehara et al.
			6,037,720 A	3/2000	Wong et al.
			6,038,148 A	3/2000	Farrington et al.
			6,046,919 A	4/2000	Madenokouji et al.
			6,050,779 A	4/2000	Nagao et al.
			6,078,511 A	6/2000	Fasullo et al.
			6,081,104 A	6/2000	Kern
			6,082,122 A	7/2000	Madenokouji et al.
			6,105,317 A	8/2000	Tomichi et al.
			6,111,188 A	8/2000	Kurokami et al.
			6,111,391 A	8/2000	Cullen
			6,111,767 A	8/2000	Handleman
			6,163,086 A	12/2000	Choo
			6,166,455 A	12/2000	Li
			6,166,527 A	12/2000	Dwellely et al.
			6,169,678 B1	1/2001	Kondo et al.
			6,219,623 B1	4/2001	Wills
			6,255,360 B1	7/2001	Domschke et al.
			6,256,234 B1	7/2001	Keeth et al.
			6,259,234 B1	7/2001	Perol
			6,262,558 B1	7/2001	Weinberg
			6,285,572 B1	9/2001	Onizuka et al.
			6,292,379 B1	9/2001	Edevold et al.
			6,301,128 B1	10/2001	Jang et al.
			6,304,065 B1	10/2001	Wittenbreder
			6,320,769 B2	11/2001	Kurokami et al.
			6,339,538 B1	1/2002	Handleman
			6,351,130 B1	2/2002	Preiser et al.
			6,369,462 B1	4/2002	Siri
			6,380,719 B2	4/2002	Underwood et al.
			6,396,170 B1	5/2002	Laufenberg et al.
			6,433,522 B1	8/2002	Siri
			6,441,597 B1	8/2002	Lethellier
			6,448,489 B2	9/2002	Kimura et al.
			6,452,814 B1	9/2002	Wittenbreder
			6,493,246 B2	12/2002	Suzui et al.
			6,507,176 B2	1/2003	Wittenbreder, Jr.
			6,531,848 B1	3/2003	Chitsazan et al.
			6,545,211 B1	4/2003	Mimura
			6,548,205 B2	4/2003	Leung et al.
			6,587,051 B2	7/2003	Takehara et al.
			6,590,793 B1	7/2003	Nagao et al.
			6,593,521 B2	7/2003	Kobayashi
			6,608,468 B2	8/2003	Nagase
			6,611,130 B2	8/2003	Chang
			6,611,441 B2	8/2003	Kurokami et al.
			6,628,011 B2	9/2003	Droppo et al.
			6,633,824 B2	10/2003	Dollar, II
			6,650,031 B1	11/2003	Goldack
			6,650,560 B2	11/2003	MacDonald et al.
			6,653,549 B2	11/2003	Matsushita et al.
			6,672,018 B2	1/2004	Shingleton
			6,678,174 B2	1/2004	Suzui et al.
			6,690,590 B2	2/2004	Stamenic et al.
			6,693,781 B1	2/2004	Kroker
			6,731,136 B2	5/2004	Knee
			6,738,692 B2	5/2004	Schienbein et al.
			6,744,643 B2	6/2004	Luo et al.
			6,765,315 B2	7/2004	Hammerstrom et al.
			6,768,047 B2	7/2004	Chang et al.

(56)

## References Cited

## U.S. PATENT DOCUMENTS

6,788,033 B2	9/2004	Vinciarelli	7,804,282 B2	9/2010	Bertele
6,788,146 B2	9/2004	Forejt et al.	7,812,701 B2	10/2010	Lee et al.
6,795,318 B2	9/2004	Haas et al.	7,839,022 B2	11/2010	Wolfs
6,801,442 B2	10/2004	Suzui et al.	7,843,085 B2	11/2010	Ledenev et al.
6,810,339 B2	10/2004	Wills	7,864,497 B2	1/2011	Quardt et al.
6,850,074 B2	2/2005	Adams et al.	7,868,599 B2	1/2011	Rahman et al.
6,882,131 B1	4/2005	Takada et al.	7,880,334 B2	2/2011	Evans et al.
6,914,418 B2	7/2005	Sung	7,893,346 B2	2/2011	Nachamkin et al.
6,919,714 B2	7/2005	Delepaut	7,900,361 B2	3/2011	Adest et al.
6,927,955 B2	8/2005	Suzui et al.	7,919,952 B1	4/2011	Fahrenbruch
6,933,627 B2	8/2005	Wilhelm	7,919,953 B2	4/2011	Porter et al.
6,936,995 B2	8/2005	Kapsokavathis et al.	7,925,552 B2	4/2011	Tarbell et al.
6,950,323 B2	9/2005	Achleitner et al.	7,944,191 B2	5/2011	Xu
6,963,147 B2	11/2005	Kurokami et al.	7,945,413 B2	5/2011	Krein
6,984,967 B2	1/2006	Notman	7,948,221 B2	5/2011	Watanabe et al.
6,984,970 B2	1/2006	Capel	7,952,897 B2	5/2011	Nocentini et al.
7,030,597 B2	4/2006	Bruno et al.	7,960,650 B2	6/2011	Richter et al.
7,031,176 B2	4/2006	Kotsopoulos et al.	7,960,950 B2	6/2011	Glovinsky
7,042,195 B2	5/2006	Tsunetsugu et al.	8,003,885 B2	8/2011	Richter et al.
7,046,531 B2	5/2006	Zocchi et al.	8,004,116 B2	8/2011	Ledenev et al.
7,053,506 B2	5/2006	Alonso et al.	8,004,117 B2	8/2011	Adest et al.
7,072,194 B2	7/2006	Nayar et al.	8,013,472 B2	9/2011	Adest et al.
7,079,406 B2	7/2006	Kurokami et al.	8,018,748 B2	9/2011	Leonard
7,087,332 B2	8/2006	Harris	8,058,747 B2	11/2011	Avrutsky et al.
7,090,509 B1	8/2006	Gilliland et al.	8,058,752 B2	11/2011	Erickson, Jr. et al.
7,091,707 B2	8/2006	Cutler	8,067,855 B2	11/2011	Mumtaz et al.
7,097,516 B2	8/2006	Werner et al.	8,077,437 B2	12/2011	Mumtaz et al.
7,099,169 B2	8/2006	West et al.	8,093,756 B2	1/2012	Porter et al.
7,126,053 B2	10/2006	Kurokami et al.	8,093,757 B2	1/2012	Wolfs
7,126,294 B2	10/2006	Minami et al.	8,098,055 B2	1/2012	Avrutsky et al.
7,138,786 B2	11/2006	Ishigaki et al.	8,102,144 B2	1/2012	Capp et al.
7,148,669 B2	12/2006	Maksimovic et al.	8,111,052 B2	2/2012	Glovinsky
7,158,359 B2	1/2007	Bertele et al.	8,116,103 B2	2/2012	Zacharias et al.
7,158,395 B2	1/2007	Deng et al.	8,138,914 B2	3/2012	Wong et al.
7,174,973 B1	2/2007	Lysaght	8,184,460 B2	5/2012	O'Brien et al.
7,193,872 B2	3/2007	Siri	8,204,709 B2	6/2012	Presher, Jr. et al.
7,218,541 B2	5/2007	Price et al.	8,289,742 B2	10/2012	Adest et al.
7,248,946 B2	7/2007	Bashaw et al.	8,415,937 B2	4/2013	Hester
7,256,566 B2	8/2007	Bhavaraju et al.	8,436,592 B2	5/2013	Saitoh
7,277,304 B2	10/2007	Stancu et al.	8,570,017 B2	10/2013	Perichon et al.
7,281,141 B2	10/2007	Elkayam et al.	2001/0023703 A1	9/2001	Kondo et al.
7,282,814 B2	10/2007	Jacobs	2001/0034982 A1	11/2001	Nagao et al.
7,291,036 B1	11/2007	Daily et al.	2002/0044473 A1	4/2002	Toyomura et al.
RE39,976 E	1/2008	Schiff et al.	2002/0056089 A1	5/2002	Houston
7,336,056 B1	2/2008	Denning	2003/0058593 A1	3/2003	Bertele et al.
7,348,802 B2	3/2008	Kasanyal et al.	2003/0058662 A1	3/2003	Baudelot et al.
7,352,154 B2	4/2008	Cook	2003/0066076 A1	4/2003	Minahan
7,371,963 B2	5/2008	Suenaga et al.	2003/0075211 A1	4/2003	Makita et al.
7,372,712 B2	5/2008	Stancu et al.	2003/0080741 A1	5/2003	LeRow et al.
7,385,380 B2	6/2008	Ishigaki et al.	2003/0214274 A1	11/2003	Lethellier
7,385,833 B2	6/2008	Keung	2004/0041548 A1	3/2004	Perry
7,394,237 B2	7/2008	Chou et al.	2004/0061527 A1	4/2004	Knee
7,420,815 B2	9/2008	Love	2004/0125618 A1	7/2004	De Rooij et al.
7,435,134 B2	10/2008	Lenox	2004/0140719 A1	7/2004	Vulih et al.
7,435,897 B2	10/2008	Russell	2004/0169499 A1	9/2004	Huang et al.
7,443,052 B2	10/2008	Wendt et al.	2004/0201279 A1	10/2004	Templeton
7,456,523 B2	11/2008	Kobayashi	2004/0201933 A1	10/2004	Blanc
7,471,014 B2	12/2008	Lum et al.	2004/0246226 A1	12/2004	Moon
7,495,419 B1	2/2009	Ju	2005/0002214 A1	1/2005	Deng et al.
7,504,811 B2	3/2009	Watanabe et al.	2005/0005785 A1	1/2005	Poss et al.
7,589,437 B2	9/2009	Henne et al.	2005/0017697 A1	1/2005	Capel
7,600,349 B2	10/2009	Liebendorfer	2005/0057214 A1	3/2005	Matan
7,602,080 B1	10/2009	Hadar et al.	2005/0057215 A1	3/2005	Matan
7,605,498 B2	10/2009	Ledenev et al.	2005/0068820 A1	3/2005	Radosevich et al.
7,612,283 B2	11/2009	Toyomura et al.	2005/0099138 A1	5/2005	Wilhelm
7,646,116 B2	1/2010	Batarseh et al.	2005/0103376 A1	5/2005	Matsushita et al.
7,709,727 B2	5/2010	Roehrig et al.	2005/0105224 A1	5/2005	Nishi
7,719,140 B2	5/2010	Ledenev et al.	2005/0121067 A1	6/2005	Toyomura et al.
7,748,175 B2	7/2010	Liebendorfer	2005/0162018 A1	7/2005	Realmuto et al.
7,759,575 B2	7/2010	Jones et al.	2005/0172995 A1	8/2005	Rohrig et al.
7,763,807 B2	7/2010	Richter	2005/0194937 A1	9/2005	Jacobs
7,780,472 B2	8/2010	Lenox	2005/0226017 A1	10/2005	Kotsopoulos et al.
7,782,031 B2	8/2010	Qiu et al.	2005/0281064 A1	12/2005	Olsen et al.
7,783,389 B2	8/2010	Yamada et al.	2006/0001406 A1	1/2006	Matan
7,787,273 B2	8/2010	Lu et al.	2006/0017327 A1	1/2006	Siri et al.
			2006/0034106 A1	2/2006	Johnson
			2006/0038692 A1	2/2006	Schnetker
			2006/0053447 A1	3/2006	Krzyzanowski et al.
			2006/0066349 A1	3/2006	Murakami

(56)

## References Cited

## U.S. PATENT DOCUMENTS

2006/0068239	A1	3/2006	Norimatsu et al.
2006/0108979	A1	5/2006	Daniel et al.
2006/0113843	A1	6/2006	Beveridge
2006/0113979	A1	6/2006	Ishigaki et al.
2006/0118162	A1	6/2006	Saelzer et al.
2006/0132102	A1	6/2006	Harvey
2006/0149396	A1	7/2006	Templeton
2006/0162772	A1	7/2006	Presher et al.
2006/0163946	A1	7/2006	Henne et al.
2006/0171182	A1	8/2006	Siri et al.
2006/0174939	A1	8/2006	Matan
2006/0176716	A1	8/2006	Balakrishnan et al.
2006/0185727	A1	8/2006	Matan
2006/0192540	A1	8/2006	Balakrishnan et al.
2006/0208660	A1	9/2006	Shinmura et al.
2006/0227578	A1	10/2006	Datta et al.
2006/0237058	A1	10/2006	McClintock et al.
2007/0013349	A1	1/2007	Bassett
2007/0030068	A1	2/2007	Motonobu et al.
2007/0044837	A1	3/2007	Simburger et al.
2007/0075689	A1	4/2007	Kinder et al.
2007/0075711	A1	4/2007	Blanc et al.
2007/0081364	A1	4/2007	Andreycaak
2007/0133241	A1	6/2007	Mumtaz et al.
2007/0147075	A1	6/2007	Bang
2007/0159866	A1	7/2007	Siri
2007/0164612	A1	7/2007	Wendt et al.
2007/0164750	A1	7/2007	Chen et al.
2007/0165347	A1	7/2007	Wendt et al.
2007/0205778	A1	9/2007	Fabbro et al.
2007/0227574	A1	10/2007	Cart
2007/0236187	A1	10/2007	Wai et al.
2007/0247877	A1	10/2007	Kwon et al.
2007/0273342	A1	11/2007	Kataoka et al.
2007/0290636	A1	12/2007	Beck et al.
2008/0024098	A1	1/2008	Hojo
2008/0080177	A1	4/2008	Chang
2008/0088184	A1	4/2008	Tung et al.
2008/0097655	A1	4/2008	Hadar et al.
2008/0106250	A1	5/2008	Prior et al.
2008/0115823	A1	5/2008	Kinsey
2008/0136367	A1	6/2008	Adest et al.
2008/0143188	A1	6/2008	Adest et al.
2008/0143462	A1	6/2008	Belisle et al.
2008/0144294	A1	6/2008	Adest et al.
2008/0147335	A1	6/2008	Adest et al.
2008/0150366	A1	6/2008	Adest et al.
2008/0164766	A1	7/2008	Adest et al.
2008/0179949	A1	7/2008	Besser et al.
2008/0218152	A1	9/2008	Bo
2008/0236647	A1	10/2008	Gibson et al.
2008/0236648	A1	10/2008	Klein et al.
2008/0238195	A1	10/2008	Shaver et al.
2008/0246460	A1	10/2008	Smith
2008/0246463	A1	10/2008	Sinton et al.
2008/0252273	A1	10/2008	Woo et al.
2008/0303503	A1	12/2008	Wolfs
2009/0039852	A1	2/2009	Fishelov et al.
2009/0066399	A1	3/2009	Chen et al.
2009/0073726	A1	3/2009	Babcock
2009/0084570	A1	4/2009	Gherardini et al.
2009/0097172	A1	4/2009	Bremicker et al.
2009/0102440	A1	4/2009	Coles
2009/0121549	A1	5/2009	Leonard
2009/0140715	A1	6/2009	Adest et al.
2009/0141522	A1	6/2009	Adest et al.
2009/0145480	A1	6/2009	Adest et al.
2009/0146667	A1	6/2009	Adest et al.
2009/0146671	A1	6/2009	Gazit
2009/0147554	A1	6/2009	Adest et al.
2009/0184746	A1	7/2009	Fahrenbruch
2009/0190275	A1	7/2009	Gilmore et al.
2009/0206666	A1	8/2009	Sella et al.
2009/0217965	A1	9/2009	Dougal et al.
2009/0224817	A1	9/2009	Nakamura et al.
2009/0237042	A1	9/2009	Glovinski
2009/0237043	A1	9/2009	Glovinski
2009/0242011	A1	10/2009	Proisy et al.
2009/0273241	A1	11/2009	Gazit et al.
2009/0282755	A1	11/2009	Abbott et al.
2009/0284998	A1	11/2009	Zhang et al.
2009/0322494	A1	12/2009	Lee
2010/0001587	A1	1/2010	Casey et al.
2010/0052735	A1	3/2010	Burkland et al.
2010/0085670	A1	4/2010	Palaniswami et al.
2010/0124027	A1	5/2010	Handelsman et al.
2010/0127571	A1	5/2010	Hadar et al.
2010/0139743	A1	6/2010	Hadar et al.
2010/0176773	A1	7/2010	Capel
2010/0181957	A1	7/2010	Goeltner
2010/0214808	A1	8/2010	Rodriguez
2010/0244575	A1	9/2010	Coccia et al.
2010/0269430	A1	10/2010	Haddock
2010/0277001	A1	11/2010	Wagoner
2010/0282290	A1	11/2010	Schwarze et al.
2010/0294528	A1	11/2010	Sella et al.
2010/0294903	A1	11/2010	Shmukler et al.
2010/0297860	A1	11/2010	Shmukler et al.
2010/0301991	A1	12/2010	Sella et al.
2010/0308662	A1	12/2010	Schatz et al.
2011/0006743	A1	1/2011	Fabbro
2011/0037600	A1	2/2011	Takehara et al.
2011/0043172	A1	2/2011	Dearn
2011/0079263	A1	4/2011	Avrutsky
2011/0084553	A1	4/2011	Adest et al.
2011/0114154	A1	5/2011	Lichy et al.
2011/0115295	A1	5/2011	Moon et al.
2011/0121652	A1	5/2011	Sella et al.
2011/0125431	A1	5/2011	Adest et al.
2011/0133552	A1	6/2011	Binder et al.
2011/0140536	A1	6/2011	Adest et al.
2011/0181251	A1	7/2011	Porter et al.
2011/0181340	A1	7/2011	Gazit
2011/0210611	A1	9/2011	Ledenev et al.
2011/0254372	A1	10/2011	Haines et al.
2011/0260866	A1	10/2011	Avrutsky et al.
2011/0267859	A1	11/2011	Chapman
2011/0271611	A1	11/2011	Maracci et al.
2011/0273015	A1	11/2011	Adest et al.
2011/0273016	A1	11/2011	Adest et al.
2011/0285205	A1	11/2011	Ledenev et al.
2011/0290317	A1	12/2011	Naumovitz et al.
2011/0291486	A1	12/2011	Adest et al.
2011/0316346	A1	12/2011	Porter et al.
2012/0007613	A1	1/2012	Gazit
2012/0019966	A1	1/2012	DeBoer
2012/0032515	A1	2/2012	Ledenev et al.
2012/0081009	A1	4/2012	Shteynberg et al.
2012/0091810	A1	4/2012	Aiello et al.

## FOREIGN PATENT DOCUMENTS

DE	19737286	A1	3/1999
DE	102005030907	A1	1/2007
DE	102008057874	A1	5/2010
EP	419093	A2	3/1991
EP	420295	A1	4/1991
EP	604777	A1	7/1994
EP	756178	A2	1/1997
EP	827254	A2	3/1998
EP	1039621	A2	9/2000
EP	1047179	A1	10/2000
EP	1330009	A2	7/2003
EP	1503490	A1	2/2005
EP	1531542	A2	5/2005
EP	1531545	A2	5/2005
EP	1657557	A1	5/2006
EP	1657797	A1	5/2006
EP	1887675	A2	2/2008
EP	2048679	A1	4/2009
EP	2315328	A2	4/2011
EP	2393178	A2	12/2011
ES	2249147	A1	3/2006
ES	2249149	A1	3/2006

(56)

## References Cited

## FOREIGN PATENT DOCUMENTS

GB	2476508	A	6/2011
GB	2480015	A	11/2011
GB	2480015	B	11/2011
JP	61065320	A	4/1986
JP	8009557	A	1/1996
JP	11041832	A	2/1999
JP	11103538	A	4/1999
JP	11206038	A	7/1999
JP	11289891	A	10/1999
JP	11318042	A	11/1999
JP	2000174307	A	6/2000
JP	2000339044	A	12/2000
JP	2001189476	A	7/2001
JP	2002300735	A	10/2002
JP	2003124492	A	4/2003
JP	2003134667	A	5/2003
JP	2004194500	A	7/2004
JP	2004260944	A	9/2004
JP	2004334704	A	11/2004
JP	2005192314	A	7/2005
JP	2007058845	A	3/2007
WO	9313587	A1	7/1993
WO	9613093	A1	5/1996
WO	9823021	A2	5/1998
WO	00/00839	A1	1/2000
WO	00/21178	A1	4/2000
WO	0075947	A1	12/2000
WO	0231517	A	4/2002
WO	03050938	A2	6/2003
WO	03071655	A1	8/2003
WO	2004023278	A2	3/2004
WO	2004090993	A2	10/2004
WO	2004098261	A2	11/2004
WO	2004107543	A2	12/2004
WO	2005076444	A1	8/2005
WO	2005076445	A1	8/2005
WO	2006005125	A1	1/2006
WO	2006007198	A1	1/2006
WO	2006078685	A2	7/2006
WO	2007006564	A2	1/2007
WO	2007048421	A2	5/2007
WO	2007073951	A1	7/2007
WO	2007084196	A2	7/2007
WO	2007090476	A2	8/2007
WO	2007113358	A1	10/2007
WO	2008008528	A2	1/2008
WO	2008125915	A2	10/2008
WO	2008132551	A2	11/2008
WO	2008132553	A2	11/2008
WO	2008142480	A2	11/2008
WO	2009007782	A2	1/2009
WO	2009046533	A1	4/2009
WO	2009051853	A1	4/2009
WO	2009118682	A2	10/2009
WO	2009118683	A2	10/2009
WO	2009073868	A1	11/2009
WO	2009136358	A1	11/2009
WO	2010/002960	A1	1/2010
WO	2010065043	A1	6/2010
WO	2010065388	A1	6/2010
WO	2010072717	A1	7/2010
WO	2010078303	A2	7/2010
WO	2010094012	A1	8/2010
WO	2010134057	A1	11/2010
WO	2011011711	A2	1/2011
WO	2011017721	A1	2/2011
WO	2011023732	A2	3/2011
WO	2011059067	A1	5/2011
WO	2011074025	A1	6/2011

## OTHER PUBLICATIONS

Mohammad Reza Amini et al., "Quasi REsonant DC Link Inverter with a Simple Auxiliary Circuit", Journal of Power Electronics, vol. 11, No. 1, Jan. 2011.

Khairy Fathy et al., "A Novel Quasi-Resonant Snubber-Assisted ZCS-PWM DC-DC Converter with High Frequency Link", Journal of Power Electronics, vol. 7, No. 2, Apr. 2007.

Cheng K.W.E., "New Generation of Switched Capacitor Converters", Department of Electrical Engineering, The Hong Kong Polytechnic University, Hung Hom, Hong Kong, Power Electronics Conference, 1998, PESC 98.

Per Karlsson, "Quasi Resonant DC Link Converters—Analysis and Design for a Battery Charger Application", Universitetstryckeriet, Lund University, 1999, ISBN 91-88934-14-4.

Hsiao Sung-Hsin et al., "ZCS Switched-Capacitor Bidirectional Converters with Secondary Output Power Amplifier for Biomedical Applications", Power Electronics Conference (IPEC) Jun. 21, 2010.

Yuang-Shung Lee et al., "A Novel QR ZCS Switched-Capacitor Bidirectional Converter", IEEE, 2007.

Antti Tolvanen et al., "Seminar on Solar Simulation Standards and Measurement Principles", May 9, 2006 Hawaii.

J.A. Eikelboom and M.J. Jansen, "Characterisation of PV Modules of New Generations—Results of tests and simulations", Jun. 2000.

Yeong-Chau Kuo et al., "Novel Maximum-Power-Point-Tracking Controller for Photovoltaic Energy Conversion System", IEEE Transactions on Industrial Electronics, vol. 48, No. 3, Jun. 2001.

C. Liu et al., "Advanced Algorithm for MPPT Control of Photovoltaic Systems", Canadian Solar Buildings Conference, Montreal, Aug. 20-24, 2004.

Chihchiang Hua and Chihming Shen, "Study of Maximum Power Tracking Techniques and Control of DC/DC Converters for Photovoltaic Power System", IEEE 1998.

Tore Skjellnes et al., "Load sharing for parallel inverters without communication", Nordic Workshop in Power and Industrial Electronics, Aug. 12-14, 2002.

Giorgio Spiazzi et al., "A New Family of Zero-Current-Switching Variable Frequency dc-dc Converters", IEEE 2000.

Nayar, C.V., M. Ashari and W.W.L. Keerthiphala, "A Gridinteractive Photovoltaic Uninterruptible Power Supply System Using Battery Storage and a Back up Diesel Generator", IEEE Transactions on Energy Conversion, vol. 15, No. 3, Sep. 2000, pp. 348-353.

Ph. Strauss et al., "AC coupled PV Hybrid systems and Micro Grids—state of the art and future trends", 3rd World Conference on Photovoltaic Energy Conversion, Osaka, Japan May 11-18, 2003.

Nayar, C.V., abstract, Power Engineering Society Summer Meeting, 2000. IEEE, 2000, pp. 1280-1282 vol. 2.

D. C. Martins et al., "Analysis of Utility Interactive Photovoltaic Generation System using a Single Power Static Inverter", Asian J. Energy Environ., vol. 5, Issue 2, (2004), pp. 115-137.

Rafael C. Beltrame et al., "Decentralized Multi String PV System With Integrated ZVT Cell", Congresso Brasileiro de Automatica / 12 a 16-setembro-2010, Bonito-MS.

Sergio Busquets-Monge et al., "Multilevel Diode-clamped Converter for Photovoltaic Generators With Independent Voltage Control of Each Solar Array", IEEE Transactions on Industrial Electronics, vol. 55, No. 7, Jul. 2008.

Soeren Baekhoej Kjaer et al., "A Review of Single-Phase Grid-Connected Inverters for Photovoltaic Modules", IEEE Transactions on Industry Applications, vol. 41, No. 5, Sep./Oct. 2005.

Office Action—JP 2011-539491—Mailing date: Mar. 26, 2013.

Supplementary European Search Report—EP08857456—Mailing Date Dec. 6, 2013.

Extended European Search Report—EP14151651.8—Mailing date: Feb. 25, 2014.

Iyomori H et al., "Three-phase bridge power block module type auxiliary resonant AC link snubber-assisted soft switching inverter for distributed AC power supply", Intelec 2003. 25th. International Telecommunications Energy Conference. Yokohama, Japan, Oct. 19-23, 2003; Tokyo, IEICE, JP, Oct. 23, 2003, pp. 650-656, XP031895550, ISBN: 978-4-88552-196-6.

Yueqing Tang, "High Power Inverter EMI characterization and Improvement Using Auxiliary Resonant Snubber Inverter", Dec. 17, 1998, XP055055241, Blacksburg, Virginia Retrieved from Internet: URL: <http://jsscholar.lib.vt.edu/theses/available/etd-012299-165108/unrestricted/THESIS.PDF>, [retrieved on Mar. 5, 2013].

Yoshida M et al., "Actual efficiency and electromagnetic noises evaluations of a single inductor resonant AC link snubber-assisted three-

(56)

**References Cited****OTHER PUBLICATIONS**

- phase soft-switching inverter", INTELEC 2003. 25th. International Telecommunications Energy Conference. Yokohama, Japan, Oct. 19-23, 2003; Tokyo, IEICE, JP, Oct. 23, 2003, pp. 721-726, XP031895560, ISBN: 978-4-88552-196-6.
- Third party observation—EP07874025.5—Mailing date: Aug. 6, 2011.
- Ciobotaru, et al., Control of single-stage single-phase PV inverter, Aug. 7, 2006.
- International Search Report and Written Opinion for PCT/IB2007/004591 dated Jul. 5, 2010.
- European Communication for EP07873361.5 dated Jul. 12, 2010.
- European Communication for EP07874022.2 dated Oct. 18, 2010.
- European Communication for EP07875148.4 dated Oct. 18, 2010.
- Chen, et al., "A New Low-Stress Buck-Boost Converter for Universal-Input PFC Applications", IEEE Applied Power Electronics Conference, Feb. 2001, Colorado Power Electronics Center Publications.
- Chen, et al., "Buck-Boost PWM Converters Having Two Independently Controlled Switches", IEEE Power Electronics Specialists Conference, Jun. 2001, Colorado Power Electronics Center Publications.
- Esram, et al., "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques", IEEE Transactions on Energy Conversion, vol. 22, No. 2, Jun. 2007, pp. 439-449.
- Walker, et al., "Photovoltaic DC-DC Module Integrated Converter for Novel Cascaded and Bypass Grid Connection Topologies-Design and Optimisation", 37th IEEE Power Electronics Specialists Conference, Jun. 18-22, 2006, Jeju, Korea.
- Geoffrey R. Walker Affidavit re: U.S. Appl. No. 11/950,307, submitted in an IDS for U.S. Appl. No. 11/950,271 on Mar. 9, 2010.
- Geoffrey R. Walker Affidavit re: U.S. Appl. No. 11/950,271, submitted in an IDS for U.S. Appl. No. 11/950,271 on Mar. 9, 2010.
- International Search Report for PCT/IB2007/004610 dated Feb. 23, 2009.
- International Search Report for PCT/IB2007/004584 dated Jan. 28, 2009.
- International Search Report for PCT/IB2007/004586 dated Mar. 5, 2009.
- International Search Report for PCT/IB2007/004643 dated Jan. 30, 2009.
- International Search Report for PCT/US2008/085736 dated Jan. 28, 2009.
- International Search Report for PCT/US2008/085754 dated Feb. 9, 2009.
- International Search Report for PCT/US2008/085755 dated Feb. 3, 2009.
- Kajihara, et al., "Model of Photovoltaic Cell Circuits Under Partial Shading", 2005 IEEE, pp. 866-870.
- Knaupp, et al., "Operation of a 10 KW PV Façade with 100 W AC Photovoltaic Modules", 1996 IEEE, 25th PVSC, May 13-17, 1996, pp. 1235-1238, Washington, DC.
- Alonso, et al., "Cascaded H-Bridge Multilevel Converter for Grid Connected Photovoltaic Generators with Independent Maximum Power Point Tracking of Each Solar Array", 2003 IEEE 34th, Annual Power Electronics Specialists Conference, Acapulco, Mexico, Jun. 15-19, 2003, pp. 731-735, vol. 2.
- Myrzik, et al., "String and Module Integrated Inverters for Single-Phase Grid Connected Photovoltaic Systems—A Review", Power Tech Conference Proceedings, 2003 IEEE Bologna, Jun. 23-26, 2003, p. 8, vol. 2.
- Chen, et al., "Predictive Digital Current Programmed Control", IEEE Transactions on Power Electronics, vol. 18, Issue 1, Jan. 2003.
- Wallace, et al., "DSP Controlled Buck/Boost Power Factor Correction for Telephony Rectifiers", Telecommunications Energy Conference 2001, INTELEC 2001, Twenty-Third International, Oct. 18, 2001, pp. 132-138.
- Alonso, "A New Distributed Converter Interface for PV Panels", 20th European Photovoltaic Solar Energy Conference, Jun. 6-10, 2005, Barcelona, Spain, pp. 2288-2291.
- Alonso, "Experimental Results of Intelligent PV Module for Grid-Connected PV Systems", 21st European Photovoltaic Solar Energy Conference, Sep. 4-8, 2006, Dresden, Germany, pp. 2297-2300.
- Enslin, "Integrated Photovoltaic Maximum Power Point Tracking Converter", IEEE Transactions on Industrial Electronics, vol. 44, No. 6, Dec. 1997, pp. 769-773.
- Lindgren, "Topology for Decentralised Solar Energy Inverters with a Low Voltage AC-Bus", Chalmers University of Technology, Department of Electrical Power Engineering, EPE '99—Lausanne.
- Nikraz, "Digital Control of a Voltage Source Inverter in a Photovoltaic Applications", 2004 35th Annual IEEE Power Electronics Specialists Conference, Aachen, Germany, 2004, pp. 3266-3271.
- Ordaz, "Evaluation Test Results of a New Distributed MPPT Converter", 22nd European Photovoltaic Solar Energy Conference, Sep. 3-7, 2007, Milan, Italy.
- Palma, "A Modular Fuel Cell, Modular DC-DC Converter Concept for High Performance and Enhanced Reliability", IEEE 2007, pp. 2633-2638.
- Quaschnig, "Cost Effectiveness of Shadow Tolerant Photovoltaic Systems", Berlin University of Technology, Institute of Electrical Energy Technology, Renewable Energy Section. EuroSun '96, pp. 819-824.
- Roman, "Intelligent PV Module for Grid-Connected PV Systems", IEEE Transactions on Industrial Electronics, vol. 52, No. 4, Aug. 2006, pp. 1066-1073.
- Roman, "Power Line Communications in Modular PV Systems", 20th European Photovoltaic Solar Energy Conference, Jun. 6-10, 2005, Barcelona, Spain, pp. 2249-2252.
- Uriarte, "Energy Integrated Management System for PV Applications", 20th European Photovoltaic Solar Energy Conference, Jun. 6-10, 2005, Barcelona, Spain, pp. 2292-2295.
- Walker, "Cascaded DC-DC Converter Connection of Photovoltaic Modules", IEEE Transactions on Power Electronics, vol. 19, No. 4, Jul. 2004, pp. 1130-1139.
- Matsui, et al., "A New Maximum Photovoltaic Power Tracking Control Scheme Based on Power Equilibrium at DC Link", IEEE, 1999, pp. 804-809.
- Hou, et al., Application of Adaptive Algorithm of Solar Cell Battery Charger, Apr. 2004.
- Stamenic, et al., "Maximum Power Point Tracking for Building Integrated Photovoltaic Ventilation Systems", 2000.
- International Preliminary Report on Patentability for PCT/IB2008/055092 dated Jun. 8, 2010.
- International Search Report for PCT/IB2008/055092 dated Sep. 8, 2009.
- International Search Report and Opinion of International Patent Application WO2009136358 (PCT/IB2009/051831), dated Sep. 16, 2009.
- Informal Comments to the International Search Report dated Dec. 3, 2009.
- PCT/IB2010/052287 International Search Report and Written Opinion dated Sep. 2, 2010.
- UK Intellectual Property office, Combined Search and Examination Report for GB1100450.4 under Sections 17 and 18 (3), Jul. 14, 2011.
- Jain, et al., "A Single-Stage Grid Connected Inverter Topology for Solar PV Systems with Maximum Power Point Tracking", IEEE Transactions on Power Electronics, vol. 22, No. 5, Sep. 2007, pp. 1928-1940.
- Lynch, et al., "Flexible DER Utility Interface System: Final Report", Sep. 2004-May 2006, Northern Power Systems, Inc., Waitsfield, Vermont B. Kroposki, et al., National Renewable Energy Laboratory Golden, Colorado Technical Report NREL/TP-560-39876, Aug. 2006.
- Schimpf, et al., "Grid Connected Converters for Photovoltaic, State of the Art, Ideas for improvement of Transformerless Inverters", NORPIE/2008, Nordic Workshop on Power and Industrial Electronics, Jun. 9-11, 2008.
- Sandia Report SAND96-2797 IUC-1290 Unlimited Release, Printed Dec. 1996, "Photovoltaic Power Systems and the National Electrical Code: Suggested Practices", by John Wiles, Southwest Technology Development Institute New Mexico State University Las Cruces, NM.

(56)

**References Cited****OTHER PUBLICATIONS**

United Kingdom Intellectual Property Office, Combined Search and Examination Report Under Sections 17 and 18(3), GB1020862.7, dated Jun. 16, 2011.

QT Technical Application Papers, "ABB Circuit-Breakers for Direct current Applications", ABB SACE S.p.A., An ABB Group Company, L.V. Breakers, Via Baioni, 35, 24123 Bergamo-Italy, Tel.: +39 035.395.111—Telefax: +39 035.395.306-433, Sep. 2007.

Woyte, et al., "Mains Monitoring and Protection in a European Context", 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, Germany, Oct. 22-26, 2001, ACHIM, WOYTE, et al., pp. 1-4.

"Implementation and testing of Anti-Islanding Algorithms for IEEE 929-2000 Compliance of Single Phase Photovoltaic Inverters", Raymond M. Hudson, Photovoltaic Specialists Conference, 2002. Conference Record of the Twenty-Ninth IEEE, May 19-24, 2002.

Fairchild Semiconductor, Application Note 9016, IGBT Basics 1, by K.S. OH Feb. 1, 2001.

"Disconnect Switches in Photovoltaic Applications", ABB, Inc., Low Voltage Control Products & Systems, 1206 Hatton Road, Wichita Falls, TX 86302, Phone 888-385-1221, 940-397-7000, Fax: 940-397-7085, 1SXU301197B0201, Nov. 2009.

Walker, "A DC Circuit Breaker for an Electric Vehicle Battery Pack", Australasian Universities Power Engineering Conference and IEAust Electric Energy Conference, Sep. 26-29, 1999.

Combined Search and Examination Report for GB1018872.0 dated Apr. 15, 2011, 2 pages.

International Search Report and Opinion of International Patent Application PCT/2009/051221, dated Oct. 19, 2009.

International Search Report and Opinion of International Patent Application PCT/2009/051222, dated Oct. 7, 2009.

Communication in EP07874025.5 dated Aug. 17, 2011.

IPRP for PCT/IB2008/055095 dated Jun. 8, 2010, with Written Opinion.

ISR for PCT/IB2008/055095 dated Apr. 30, 2009.

ISR for PCT/IL07/01064 dated Mar. 25, 2008.

IPRP for PCT/IB2007/004584 dated Jun. 10, 2009, with Written Opinion.

IPRP for PCT/IB2007/004591 dated Jul. 13, 2010, with Written Opinion.

IPRP for PCT/IB2007/004643 dated Jun. 10, 2009, with Written Opinion.

Written Opinion for PCT/IB2008/055092 submitted with IPRP dated Jun. 8, 2010.

IPRP for PCT/US2008/085754 dated Jun. 8, 2010, with Written Opinion dated Jan. 21, 2009.

IPRP for PCT/US2008/085755 dated Jun. 8, 2010, with Written Opinion dated Jan. 20, 2009.

IPRP for PCT/IB2009/051221 dated Sep. 28, 2010, with Written Opinion.

IPRP for PCT/IB2009/051222 dated Sep. 28, 2010, with Written Opinion.

IPRP for PCT/IB2009/051831 dated Nov. 9, 2010, with Written Opinion.

IPRP for PCT/US2008/085736 dated Jun. 7, 2011, with Written Opinion.

IPRP for PCT/IB2010/052287 dated Nov. 22, 2011, with Written Opinion.

ISR for PCT/IB2010/052413 dated Sep. 7, 2010.

UK Intellectual Property Office, Application No. GB1109618.7, Patents Act 1977, Examination Report Under Section 18(3), Sep. 16, 2011.

UK Intellectual Property Office, Patents Act 1977: Patents Rules Notification of Grant: Patent Serial No. GB2480015, Nov. 29, 2011.

Walker, et al. "PV String Per-Module Maximim Power Point Enabling Converters", School of Information Technology and Electrical Engineering The University of Queensland, Sep. 28, 2003.

Walker, "Cascaded DC-DC Converter Connection of Photovoltaic Modules", 33rd Annual IEEE Power Electronics Specialists Conference, PESC 2002. Conference Proceedings. CAIRNS, Queensland, Australia, Jun. 23-27, 2002; [Annual Power Electronics Specialists Conference], New York, NY: IEEE US, vol. 1, Jun. 23, 2002, pp. 24-29, XP010596060 ISBN: 978-0-7803-7262-7, figure 1.

Baggio, "Quasi-ZVS Activity Auxiliary Commutation Circuit for Two Switches Forward Converter", 32nd Annual IEEE Power Electronics Specialists Conference, PESC 2001. Conference Proceedings. Vancouver, Canada, Jun. 17-21, 2001; [Annual Power Electronics Specialists Conference] New York, NY: IEEE, US.

Illic, "Interleaved Zero-Current-Transition Buck Converter", IEEE Transactions on Industry Applications, IEEE Service Center, Piscataway, NJ, US, vol. 43, No. 6, Nov. 1, 2007, pp. 1619-1627, XP011197477 ISSN: 0093-9994, pp. 1619-1922.

Lee: "Novel Zero-Voltage-Transition and Zero-Current-Transition Pulse-Width-Modulation Converters", Power Electronics Specialists Conference, 1997, PESC '97, Record, 28th Annual IEEE St. Louis, MO, USA, Jun. 22-27, 1997, New York, NY, USA IEEE, US, vol. 1, Jun. 22, 1997, pp. 233-239, XP010241553, ISBN: 978-0-7803-3840-1, pp. 233-236.

Sakamoto, "Switched Snubber for High-Frequency Switching Converters", Electronics & Communications in Japan, Part 1—Communications, Wiley, Hoboken, NJ, US, vol. 76, No. 2, Feb. 1, 1993, pp. 30-38, XP000403018 ISSN: 8756-6621, pp. 30-35.

Duarte, "A Family of ZVX-PWM Active-Clamping DC-to-DC Converters: Synthesis, Analysis and Experimentation", Telecommunications Energy Conference, 1995, INTELEC '95, 17th International The Hague, Netherlands, Oct. 29-Nov. 1, 1995, New York, NY, US, IEEE, US, Oct. 29, 1995, pp. 502-509, XP010161283 ISBN: 978-0-7803-2750-4 p. 503-504.

IPRP for PCT/IL2007/001064 dated Mar. 17, 2009, with Written Opinion dated Mar. 25, 2008.

IPRP for PCT/IB2007/004586 dated Jun. 10, 2009, with Written Opinion.

Gao, et al., "Parallel-Connected Solar PV System to Address Partial and Rapidly Fluctuating Shadow Conditions", IEEE Transactions on Industrial Electronics, vol. 56, No. 5, May 2009, pp. 1548-1556.

IPRP PCT/IB2007/004610—date of issue Jun. 10, 2009.

Extended European Search Report—EP12176089.6—Mailing date: Nov. 8, 2012.

Gwon-Jong Yu et al: "Maximum power point tracking with temperature compensation of photovoltaic for air conditioning system with fuzzy controller", 19960513; 19960513-19960517, May 13, 1996, pp. 1429-1432, XP010208423.

Extended European Search Report—EP12177067.1—Mailing Date: Dec. 7, 2012.

GB Combined Search and Examination Report—GB1200423.0—Mailing date: Apr. 30, 2012.

GB Combined Search and Examination Report—GB1201499.9—Mailing date: May 28, 2012.

GB Combined Search and Examination Report—GB1201506.1—Mailing date: May 22, 2012.

"Study of Energy Storage Capacitor Reduction for Single Phase PWM Rectifier", Ruxi Wang et al., Virginia Polytechnic Institute and State University, Feb. 2009.

"Multilevel Inverters: A Survey of Topologies, Controls, and Applications", José Rodríguez et al., IEEE Transactions on Industrial Electronics, vol. 49, No. 4, Aug. 2002.

Extended European Search Report—EP08878650A—Mailing date: Mar. 28, 2013.

Satcon Solstice—Satcon Solstice 100 kW System Solution Sheet—2010.

John Xue, "PV Module Series String Balancing Converters", University of Queensland—School of Information Technology & Electrical Engineering, Nov. 6, 2002.

Robert W. Erickson, "Future of Power Electronics for Photovoltaics", IEEE Applied Power Electronics Conference, Feb. 2009.

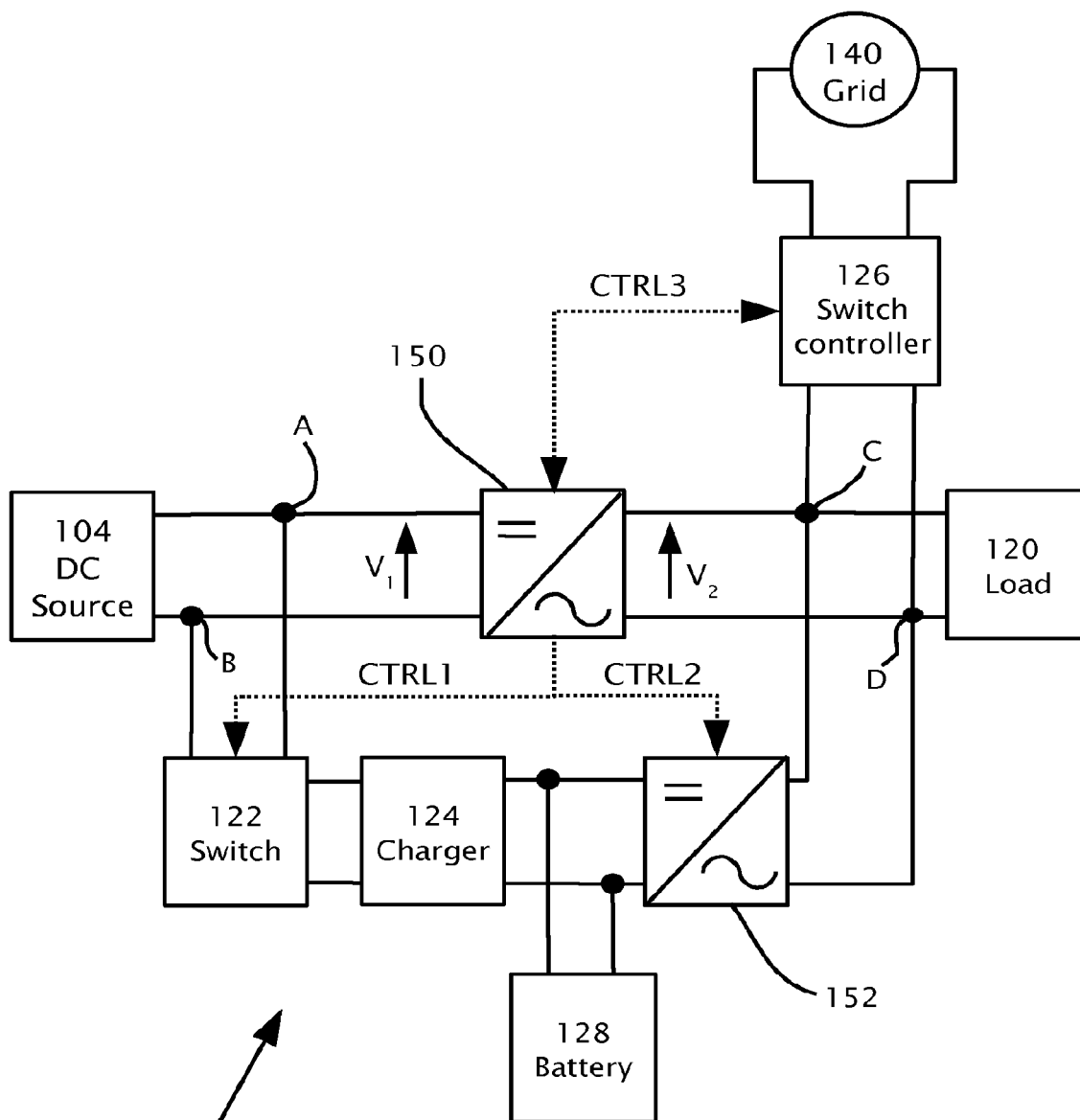
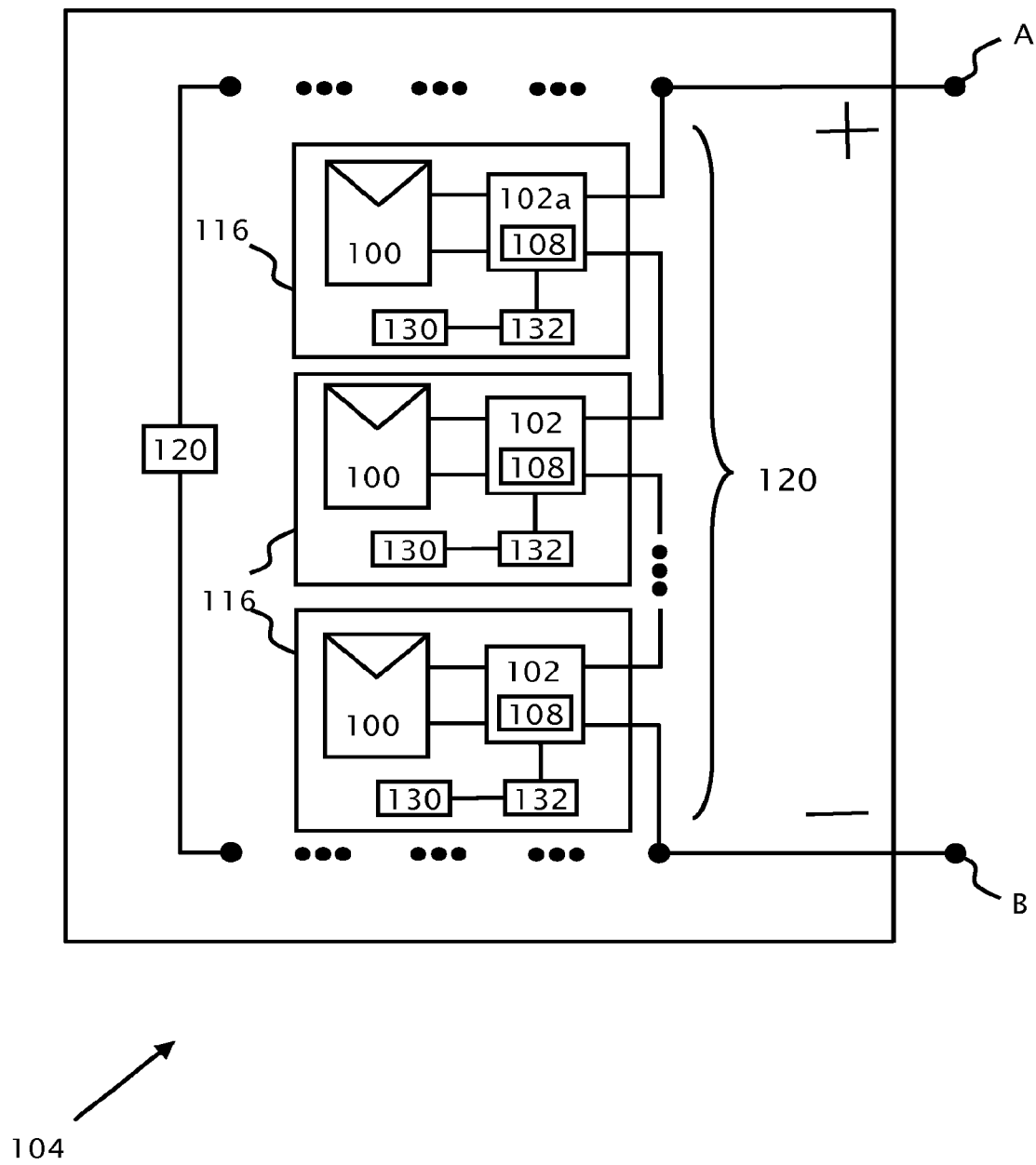


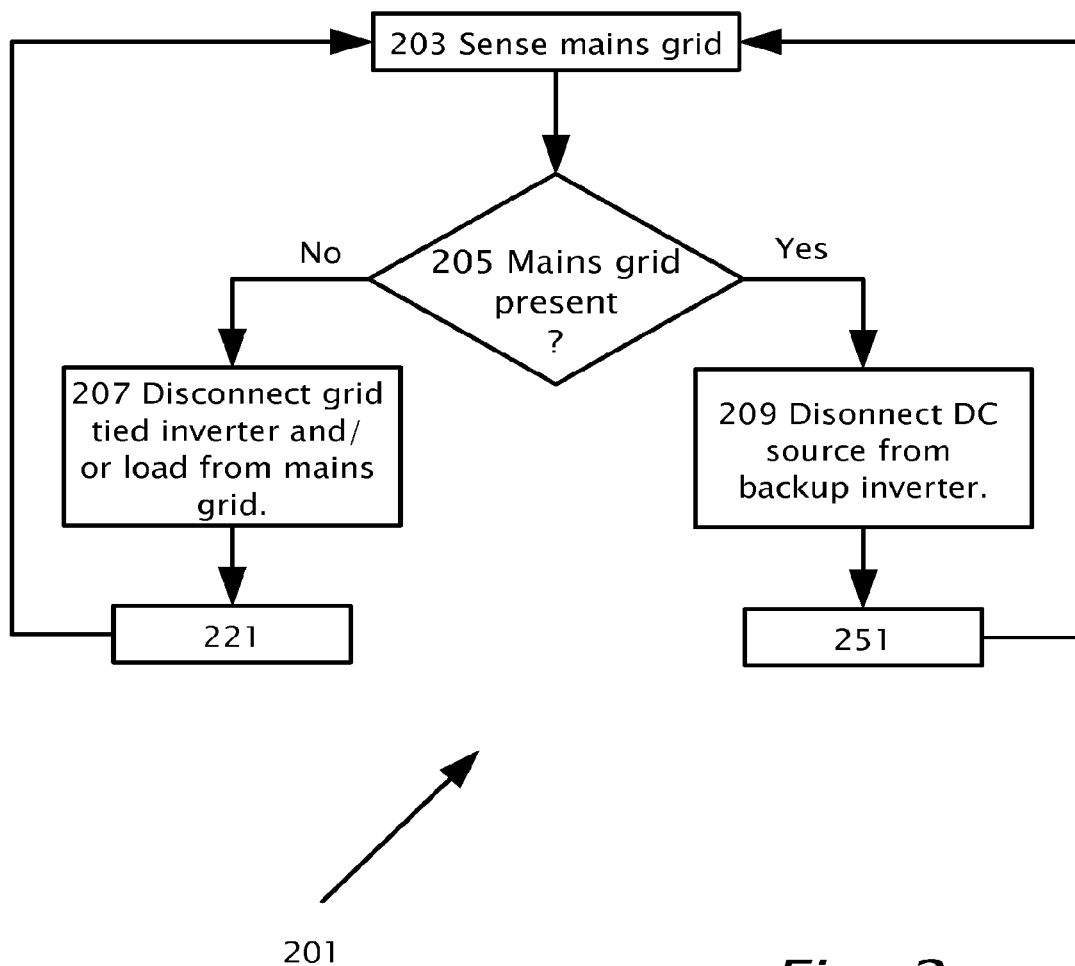
Fig. 1a

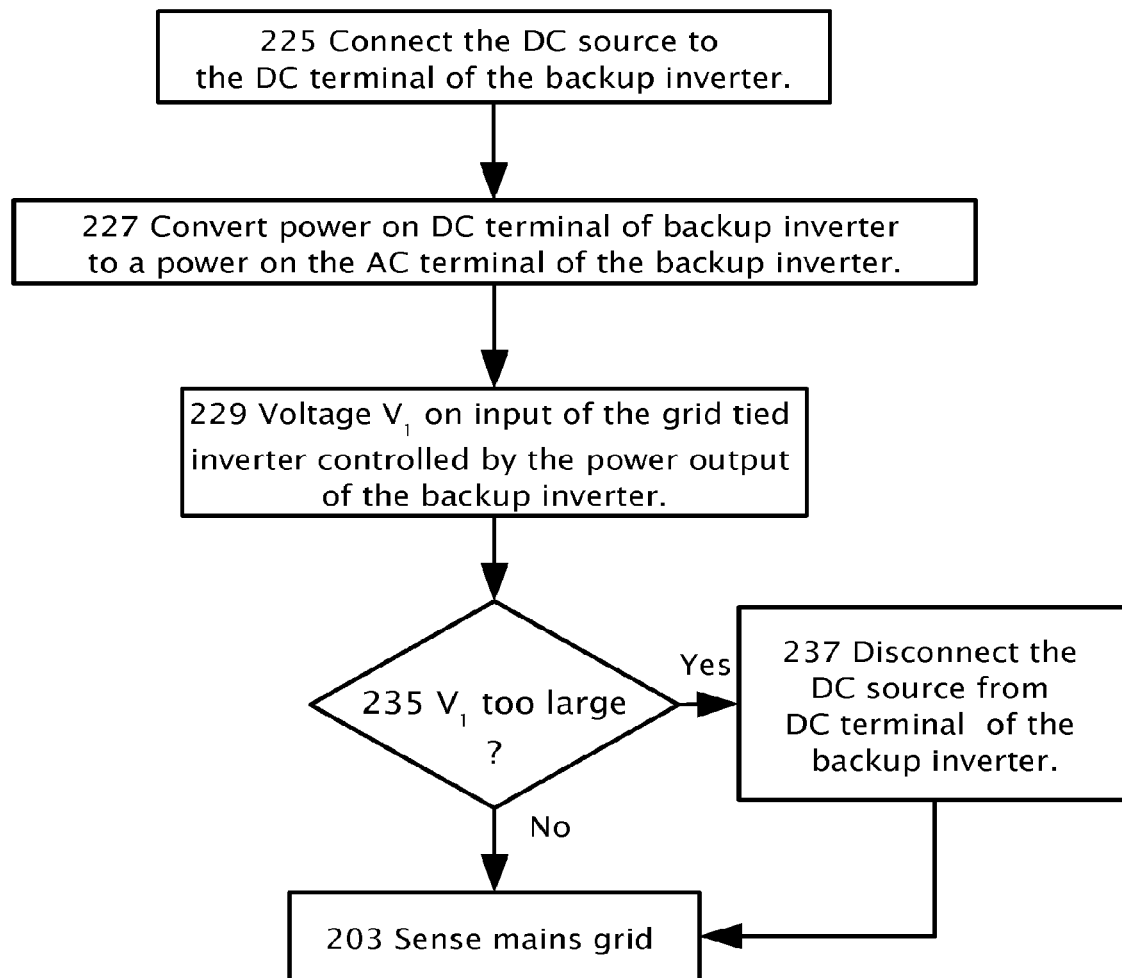
10



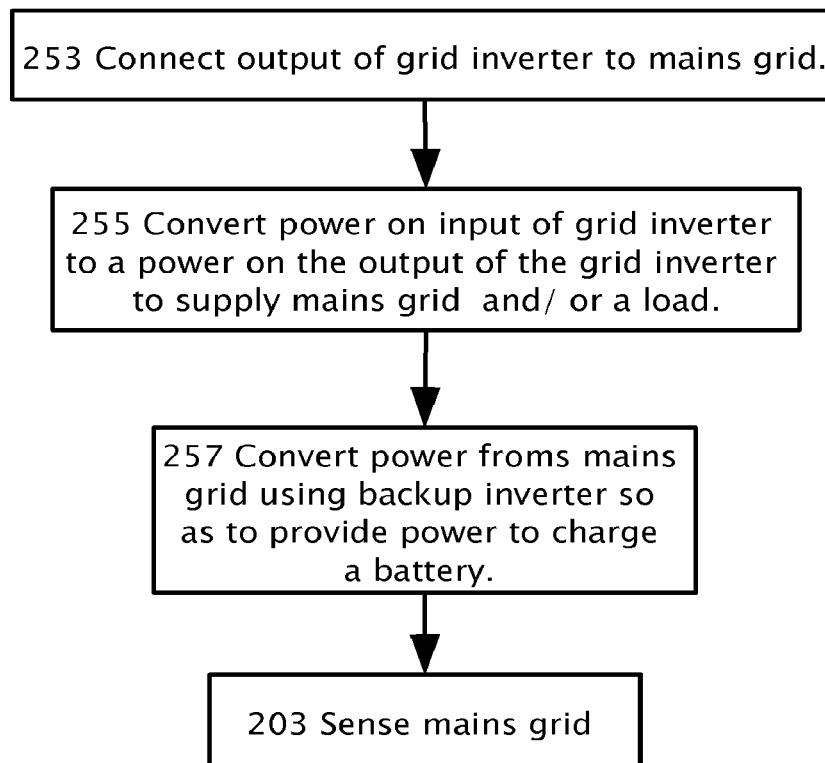


*Fig. 1b*

*Fig. 2a*

*Fig. 2b*

221



251

*Fig. 2c*

1

**DUAL USE PHOTOVOLTAIC SYSTEM****CROSS REFERENCE TO RELATED APPLICATION**

This application is a continuation of U.S. patent application Ser. No. 12/957,490, filed Dec. 1, 2010, which claims the benefit of priority from U.S. Provisional Patent Application No. 61/265,734, which was filed on Dec. 1, 2009, the disclosures of which are incorporated herein by reference.

**BACKGROUND****1. Technical Field**

The present invention relates to a hybrid photovoltaic system which features both power grid tied operation and battery charging operation.

**2. Description of Related Art**

Utility networks provide an electrical power system to utility customers. The distribution of electric power from utility companies to customers utilizes a network of utility lines connected in a grid-like fashion, referred to as a power grid. The power grid may consist of many independent energy sources energizing the grid in addition to utility companies energizing the grid, with each independent energy source being referred to as a distributed power (DP) generation system. The modern utility network includes the utility power source, consumer loads, and the distributed power generation systems which also supply electrical power to the network. The number and types of distributed power generation systems is growing rapidly and can include photovoltaics, wind, hydro, fuel cells, storage systems such as battery, super-conducting flywheel, and capacitor types, and mechanical devices including conventional and variable speed diesel engines, Stirling engines, gas turbines, and micro-turbines. These distributed power generation systems are typically connected to the utility network such that they operate in parallel with the utility power sources.

The term "DC source" as used herein refers to and includes DC available from photovoltaics cells, wind powered DC generators, hydro powered turbines, fuel cells, storage systems such as battery, super-conducting flywheel, and capacitor types, and mechanical devices including conventional and variable speed diesel engines, stirling engines, gas turbines, and micro-turbines.

**BRIEF SUMMARY**

According to an embodiment of the present invention there is provided a system for providing power from a direct current (DC) source to the power grid. The system includes a first inverter with an input and an output. The input is adapted to connect to the DC source. A first switch is disposed between the output and the power grid. A second inverter has a DC terminal and an alternating current (AC) terminal. The AC terminal is adapted to connect in parallel with the output of the first inverter. A battery is adapted to connect to the DC terminal of the second inverter. A second switch connects between the DC terminal of the second inverter and the input of the first inverter. The second switch also connects the DC source to the battery. The system may further include a charging circuit adapted to be disposed between the input and the DC terminal. A load connects to the output.

According to an embodiment of the present invention there is provided a method featuring both grid tied operation and battery charging operation, the method using a hybrid photovoltaic system. Two inverters are used during off grid opera-

2

tion of the hybrid photovoltaic system. The hybrid photovoltaic system includes the first inverter with an input and an output. A direct current (DC) source is connected to the input. A first switch is disposed between the output and the power grid. A second inverter has a DC terminal and an AC terminal. The AC terminal is connected in parallel with the output of the first inverter. A battery connects to the DC terminal. A second switch is disposed between the DC terminal and the input. The method senses absence of the power grid. Upon sensing the absence of the power grid, the power grid is disconnected from the output and the AC terminal with the first switch. The DC source is connected to the DC terminal with the second switch, thereby shunting the input of the first inverter with the DC terminal of the second inverter. Power on the DC terminal of the second inverter may typically be converted to an output power on the AC terminal of the second inverter. The output power typically provides a local grid to the load and the output of the first inverter. Voltage of the input of the first inverter may be controlled to a voltage value based on the local grid and/or the output power provided by the second inverter. Connection to the DC terminal with the second switch may be disconnected when a difference between voltage of the input and the voltage value exceeds a predetermined value. Connection to the DC terminal with the second switch typically allows the DC source to charge the battery. The control of voltage of the input of the first inverter may be performed by the first inverter. The control of voltage of the input of the first inverter may be by adjusting a parameter of the local grid. The local grid parameter may be adjusted by the backup inverter. The parameter may be a frequency, a phase angle, a voltage or a current. The control of voltage of the input of the first inverter may alternatively be performed by a circuit connected in series between the second switch and the DC terminal of the second inverter.

During on grid operation the method senses presence of the power grid. Based on the presence of the grid the DC source is disconnected from the DC terminal of the second inverter with the second switch, when the power grid is present. The output and the AC terminal are connected to the power grid with the first switch. Power on the input of the first inverter is typically converted to an output power on the output of the first inverter. The output power preferably supplies the power grid and/or a load. Power on the AC terminal of the second inverter is typically converted to a power on the DC terminal of the second inverter. The power on the DC terminal preferably charges the battery.

According to an embodiment of the present invention there is provided a power system which includes a power inverter, a backup inverter and a direct current (DC) source. The power inverter and the backup inverter are interconnected at respective outputs. A switch may be adapted to interconnect the inputs of the power inverter and the backup inverter and to connect the inputs to the DC source when a power grid is not available. When the power grid is available the switch may be adapted to disconnect the input of the backup inverter from the DC source.

The power system may further include a second switch adapted to connect the outputs of the power inverter and the backup inverter to the power grid when the power grid is available. When the power grid is not available the second switch adapted to disconnect the outputs of the backup inverter and the power inverter from the power grid. A charging circuit is typically adapted to be disposed between the DC source and the input of the backup inverter. A battery may be connected in parallel at the input of the backup inverter.

These, additional, and/or other aspects and/or advantages of the present invention are set forth in the detailed descrip-

tion which follows; possibly inferable from the detailed description; and/or learnable by practice of the present invention.

### BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

FIG. 1a shows a hybrid photovoltaic system according to an embodiment of the present invention;

FIG. 1b shows further details of a DC supply according to an exemplary embodiment of the present invention;

FIG. 2a shows a method for performing off grid or on grid operation of the hybrid photovoltaic system shown in FIGS. 1a and 1b, according to an embodiment of the present invention;

FIG. 2b shows more detailed method steps for off grid operation shown in FIG. 2a, according to an embodiment of the present invention; and

FIG. 2c more detailed method steps for on grid operation shown in FIG. 2a, according to an embodiment of the present invention.

The foregoing and/or other aspects will become apparent from the following detailed description when considered in conjunction with the accompanying drawing figures.

### DETAILED DESCRIPTION

Reference will now be made in detail to aspects of the present invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to the like elements throughout. The aspects are described below to explain the present invention by referring to the figures.

Before explaining embodiments of the invention in detail, it is to be understood that the invention is not limited in its application to the details of design and the arrangement of the components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

By way of introduction, aspects of the present invention are directed primarily towards off grid operation of a hybrid photovoltaic system and possible benefits of using a lower power rated and cheaper standard backup inverter to provide a local grid. The local grid may additionally be used to derive additional circuit control function benefits from an offline main grid tied inverter which is typically higher power rated, more expensive and provides more functionality.

The term “hybrid” as used herein refers off-grid and/or on grid operation of a photovoltaic system. Equivalently, the term “hybrid” as used herein may refer to a photovoltaic system which is both/either grid connected or battery connected. Operation of a “hybrid photovoltaic system” may typically include supplying AC power to a power grid and/or load and/or DC power to the battery. AC power present on the power grid, leads to an “on grid” operation of the hybrid photovoltaic system. Otherwise the absence of AC power on the power grid leads to an “off grid” operation of the hybrid photovoltaic system. Another operating factor may include nighttime or daytime operation of the hybrid photovoltaic system in either off grid or on grid operation. Also consideration of whether or not the photovoltaic array is illuminated or not or illuminated to a sufficient level leads to the load and/or power grid being supplied by a number of combinations. The

number of combinations for example may be to supply the load solely from the photovoltaic array, the photovoltaic array and power grid, the power grid alone, solely from the battery, the photovoltaic array and the battery or the photovoltaic array and the battery and the power grid.

Referring now to the drawings, reference is now made to FIG. 1a which shows a hybrid photovoltaic system 10 according to an embodiment of the present invention. System 10 typically includes a direct current (DC) source 104, grid tied inverter 150, load 120, grid switch controller 126, backup switch 122, charger 124, battery 128 and backup inverter 152. DC source 104 may typically be a bank of interconnected batteries, photovoltaic arrays, DC generator or DC producing fuel cells. DC source is connected at nodes A and B to an input of grid tied inverter 150. Grid tied inverter 150 typically may be rated to perform a conversion of 10000 watts of DC power provided by DC source 104 to substantially 10000 watts of alternating current (AC) power on the output of inverter 150 at nodes C and D. The conversion typically involves a maximum power point tracking (MPPT) algorithm utilized by inverter 150 such that inverter 150 sets the input voltage ( $V_1$ ) to inverter 150.

Output of inverter 150 at nodes C and D is connected to the input of grid switch controller 126, load 120 and the alternating current (AC) side of backup inverter 152. Backup inverter 152 is typically rated at 1000 watts. Load 120 typically is an AC supply to a domestic residence. The domestic supply receives the AC supply from power grid 140 and/or AC voltage ( $V_2$ ) provided by inverter 150. Grid switch controller 126 typically senses the presence or absence of power grid 140 to provide a status of grid 140. The status of grid 140 is typically conveyed to grid tied inverter 150 using bi-directional control line CTRL3. Grid switch controller 126 typically connects and reconnects grid 140 to nodes C and D. Grid switch controller 126 typically includes a double pole switch which connects and reconnects grid 140 to nodes C and D.

An input to backup switch 122 connects at nodes A and B. The output of switch 122 connects to the input of charging circuit 124. Backup switch 122 typically connects and reconnects the output of DC supply 104 to the input of charging circuit 124. Charging circuit 124 typically may be a DC to DC converter or a typically charge circuit which uses a linear regulator. According to one aspect of the present invention, charging circuit 124 may not be required and backup switch 122 typically connects and reconnects the output of DC supply 104 to the input of backup inverter 152. Placed in parallel across the input of backup inverter 152 is a battery 128. Backup inverter 152 typically operates in a bi-directional mode of power conversion. The bi-directional mode of inverter 152 converts AC power to DC power and vice versa. When grid 140 is not present (i.e. off grid operation), DC power from DC source 104 and/or battery 128 is converted to AC power on nodes C and D. When grid 140 is present (i.e. on grid operation), backup inverter 152 converts AC power from grid 140 and/or AC power from grid tied inverter 150 to a DC power which charges battery 128. The DC power which charges battery 128 in on grid mode, is typically applied with the input of charging circuit isolated from DC source 104 via backup switch 122. The direction of power conversion of backup inverter 152 is from a control signal applied to control line CTRL2 from inverter 150. The operation of backup switch 122 is from a control signal applied to control line CTRL3 from inverter 150. Control signals between grid switch controller 126, grid tied inverter 150, backup switch 122 and backup inverter 152 may be wireless or by power line communications.

Reference is now made to FIG. 1b which shows further details of DC supply 140 according to an exemplary embodiment of the present invention. DC power is supplied by DC source 140 at positive and negative nodes A and B respectively, by parallel connected photovoltaic strings 120. Details of only one of strings 120 are shown explicitly. In each of strings 120, direct current power sources 116 are serially connected. Each direct current power source 116 includes a photovoltaic panel 101 connected to an electronic module or photovoltaic module 102. Outputs of photovoltaic modules 102 are connected in series to form serial string 120. Photovoltaic modules 102 may be direct current (DC) to DC converters such as a buck circuit, boost circuit or buck-boost circuit. Attached to photovoltaic modules 102 is a processor 132 which accesses a memory 130. A transceiver 108 is attached to the output of electronic module 102 and to processor 132. According to a feature of the present invention, one of photovoltaic modules 102 referenced 102a is a master electronic module 102a of string 120 and controls and communicates with the other modules, i.e. slave modules 102 via power line communications or wireless link. According to this exemplary use of DC source 140, control of input voltage  $V_1$  may be an independent control such that inverter 150 sets the input voltage ( $V_1$ ) to inverter 150 and/or that inverter 150 instructs (via power line communication) DC-DC converters 102 to set the input voltage ( $V_1$ ) to inverter 150.

Reference is now made to FIG. 2a which shows a method 201 according to an embodiment of the present invention. Method 201 performs off grid or on grid operation of hybrid photovoltaic system 10 shown in FIGS. 1a and 1b. During off grid operation, DC source 104 typically supplies battery 128 and/or load 120 using backup inverter 152. During on grid operation, DC source 104 typically supplies power grid 140 and/or load 120 using grid tied inverter 150 and with battery 128 being charged using backup inverter 152.

Typically grid switch controller 126 senses the presence or absence of power grid 140 in step 203. In decision 205, if power grid 140 absent, connection to grid 140 to nodes C and D is disconnected using switch controller 126 (step 207). Grid switch controller 126 typically isolates both live and neutral of power grid 140 from nodes C and D using a double pole single throw switch. Once grid 140 is disconnected in step 207, off grid operation of system 10 continues by use of method 221 applied to system 10.

In decision 205, if power grid 140 is present, connection to grid 140 at nodes C and D using switch controller 126 typically disconnects DC source 104 from the input of backup inverter 152 and/or charge circuit 124 (step 209). With DC source 104 disconnected from the input of backup inverter 152 and/or charge circuit 124 on grid operation of system 10 continues by use of method 251 applied to system 10.

Reference is now made to FIG. 2b which shows method 221 in greater detail, according to an embodiment of the present invention. With connection to grid 140 disconnected using switch controller 126 in step 207, DC source 104 is connected (step 225) to the input of charger circuit 124. According to one aspect of the present invention, charging circuit 124 may not be required and backup switch 122 typically connects the output of DC supply 104 to the input or DC terminal of backup inverter 152. DC power from the output of charger circuit 124 or DC source 104 on the input of backup inverter 152, is then converted to an AC voltage ( $V_2$ ) power on the output or AC terminal of backup inverter 152 (step 227). The AC voltage ( $V_2$ ) power now serves as a local grid. The local grid may be sensed by grid tied inverter 150 on the AC side of grid tied inverter 150. Typically, the frequency of the local grid may be made to vary by backup inverter 152 as an

indication to grid tied inverter 150 of loading on backup inverter 152. The frequency of the local grid may be made to vary in a range from 49 hertz to 51 hertz in increments of 0.1 hertz. Alternatively the phase angle, current or voltage of the local grid may be made to vary by backup inverter 152 as an indication to grid tied inverter 150 of loading on backup inverter 152. Loading on backup inverter 152 may be dependent on the state of charge/discharge of battery 128, power demand by load 120 and the amount of power supplied by DC source 104. The indication is typically used by grid tied inverter 150 to control a maximum level of input voltage ( $V_1$ ) on the input of inverter 150 and the input of charger circuit 124. The level of input voltage ( $V_1$ ) on the input of inverter 150 typically ranges from 120 volts to an upper maximum of 140 volts. In decision 235 if voltage level ( $V_1$ ) exceeds the upper maximum of 140 volts, DC source 104 is disconnected from the input of charger 124 (step 237) using backup switch 122. Otherwise sensing presence of power grid 140 continues with step 203.

Reference is now made to FIG. 2c which shows method 251 in greater detail according to an aspect of the present invention. With DC source 104 disconnected from the input of backup inverter 152 and/or charge circuit 124 in step 209, the output of grid tied inverter 150 at nodes C and D is connected to power grid 140 via switch controller 126. DC power on the input of grid tied inverter 150 is converted to an output AC power on nodes C and D (step 255). The output AC power supplies power 140 and/or load 120. The output AC power is additionally converted by backup inverter 152 to a DC power on the DC side of backup inverter 152 (step 257). The DC power charges battery 128 is typically controlled by backup inverter 152 and/or grid tied inverter 150. Sensing of power grid 140 continues with step 203.

By way of numerical example a DC-DC module 102 has a typical maximum output current of 16.4 A. Assuming minimum charger 124 voltage will be 120V, the total power on one string 120 is limited to  $16.4 \text{ A} \times 120\text{V} \approx 2000 \text{ W}$ . If more than 2000 Watts are installed on one string 120, system 10 will still work. Module 102 will be current limited and the total number of strings will not supply more than 2000 Watts during off-grid/charge mode.

By way of another numerical example, a 3240 Kilowatt PV system 10 which has 2 strings 120 of 9 modules 102, where each module 102 is rated at 180 watts. Each string 120 power will be  $9 \times 180 \text{ W} = 1620 \text{ W}$ . In on grid mode,  $V_1 = 250\text{--}500\text{V}$ , total string current = 6.48–12.96 A and each string 120 current = 3.24–6.48 A. In on grid mode,  $V_1 = 120\text{--}140 \text{ V}$ , total string current = 23.1–27 A and each string 120 current = 11.5–13.5 A.

The term “DC source” as used herein refers to and includes DC available from photovoltaics cells, wind powered DC generators, hydro powered turbines, fuel cells, storage systems such as battery, super-conducting flywheel, and capacitor types, and mechanical devices including conventional and variable speed diesel engines, Stirling engines, gas turbines, and micro-turbines.

The term “comprising” as used herein, refers to an open group of elements for example, comprising an element A and an element B means including one or more of element A and one or more of element B and other elements other than element A and element B may be included.

The terms “sensing” and “measuring” are used herein interchangeably.

The definite articles “a”, “an” is used herein, such as “an inverter”, “a switch” have the meaning of “one or more” that is “one or more inverters or “one or more switches”.

Examples of various features/aspects/components/operations have been provided to facilitate understanding of the disclosed embodiments of the present invention. In addition, various preferences have been discussed to facilitate understanding of the disclosed embodiments of the present invention. It is to be understood that all examples and preferences disclosed herein are intended to be non-limiting.

Although selected embodiments of the present invention have been shown and described individually, it is to be understood that at least aspects of the described embodiments may be combined. Also although selected embodiments of the present invention have been shown and described, it is to be understood the present invention is not limited to the described embodiments. Instead, it is to be appreciated that changes may be made to these embodiments without departing from the principles and spirit of the invention, the scope of which is defined by the claims and the equivalents thereof.

We claim:

1. A system comprising a first inverter, a second inverter, a switch, and direct-current power nodes; wherein alternating-current terminals of the first inverter are connected to alternating-current terminals of the second inverter; and wherein the direct-current power nodes are connected to direct-current terminals of the first inverter and connected through the switch to direct-current terminals of the second inverter.
2. The system of claim 1, further comprising a second switch and alternating-current power nodes, wherein the alternating-current power nodes are connected through the second switch to the alternating-current terminals of the first inverter and the alternating-current terminals of the second inverter.
3. The system of claim 2, further comprising a controller configured to:
  - close the second switch in response to a presence of an external energy source energizing the alternating-current power nodes; and
  - open the second switch in response to an absence of the external energy source energizing the alternating-current power nodes.
4. The system of claim 2, further comprising a controller configured to:
  - open the switch in response to a presence of an external energy source energizing the alternating-current power nodes; and
  - close the switch in response to an absence of the external energy source energizing the alternating-current power nodes.
5. The system of claim 2, the second inverter being configured to:
  - convert alternating-current power on the alternating-current terminals of the second inverter to direct-current power on the direct-current terminals of the second inverter in response to a presence of an external energy source energizing the alternating-current power nodes; and
  - convert direct-current power on the direct-current terminals of the second inverter to alternating-current power on the alternating-current terminals of the second inverter in response to an absence of the external energy source energizing the alternating-current power nodes.
6. The system of claim 2, wherein the system is configured to operate in a plurality of modes when a load is connected to the alternating-current terminals of the first inverter and the alternating-current terminals of the second inverter, a battery is connected to the direct-current terminals of the second inverter, a power source is connected to the direct-current

power nodes, and a power grid is connected to the alternating-current power nodes, the plurality of modes including at least one of:

- the system being configured to supply power to the load solely from the power source;
- the system being configured to supply power to the load solely from the power grid;
- the system being configured to supply power to the load solely from the battery;
- the system being configured to supply power to the load solely from the power source and the power grid;
- the system being configured to supply power to the load solely from the power source and the battery; and
- the system being configured to supply power to the load solely from the power source, the battery, and the power grid.

7. The system of claim 1, further comprising a battery connected to the direct-current terminals of the second inverter.

8. The system of claim 7, further comprising a charging circuit connected between the battery and the direct-current power nodes through the switch.

9. The system of claim 1, further comprising a power source connected to the direct-current power nodes.

10. The system of claim 1, further comprising a load connected to the alternating-current terminals of the first inverter and the alternating-current terminals of the second inverter.

11. A method comprising:

- connecting direct-current terminals of a first inverter to direct-current terminals of a second inverter in response to sensing a power grid not being energized, the direct-current terminals of the first inverter being connected to a power source, and alternating-current terminals of the first inverter and alternating-current terminals of the second inverter being connected to a load; and
- disconnecting the direct-current terminals of the first inverter from the direct-current terminals of the second inverter in response to sensing the power grid being energized.

12. The method of claim 11, further comprising: connecting the alternating-current terminals of the first inverter and the alternating-current terminals of the second inverter to the power grid in response to the sensing of the power grid being energized; and disconnecting the alternating-current terminals of the first inverter and the alternating-current terminals of the second inverter from the power grid in response to the sensing of the power grid not being energized.

13. The method of claim 11, further comprising: the sensing of the power grid being energized and not being energized.

14. The method of claim 11, further comprising: converting, with the first inverter, direct-current power received from the power source to alternating-current power output to the power grid and to the load in response to the sensing of the power grid being energized.

15. The method of claim 11, further comprising: converting, with the second inverter, direct-current power received from the power source to alternating-current power output to the load in response to the sensing of the power grid not being energized.

16. The method of claim 11, further comprising: converting, with the second inverter, direct-current power received from a battery to alternating-current power output to the load in response to the sensing of the power grid not being energized.



17. The method of claim 11, further comprising:  
charging a battery connected the direct-current terminals  
of the second inverter with power provided from the  
power source or from the power grid.
18. The method of claim 17, the charging comprising: 5  
converting, with the second inverter, alternating-current  
power provided from the first inverter or from the power  
grid to direct-current power output to the battery in  
response to the sensing of the power grid being ener-  
gized. 10
19. The method of claim 17, the charging comprising:  
charging the battery from the power source through a con-  
nection of the direct-current terminals of the second  
inverter to the direct-current terminals of the first  
inverter made in response to the sensing the power grid 15  
not being energized.
20. The method of claim 19, further comprising:  
disconnecting the battery and the direct-current terminals  
of the second inverter from the power source and from  
the direct-current terminals of the first inverter in 20  
response to sensing a voltage across the direct-current  
terminals of the first inverter exceeding a predetermined  
threshold.

\* \* \* \* \*